Protocols for HMA Design

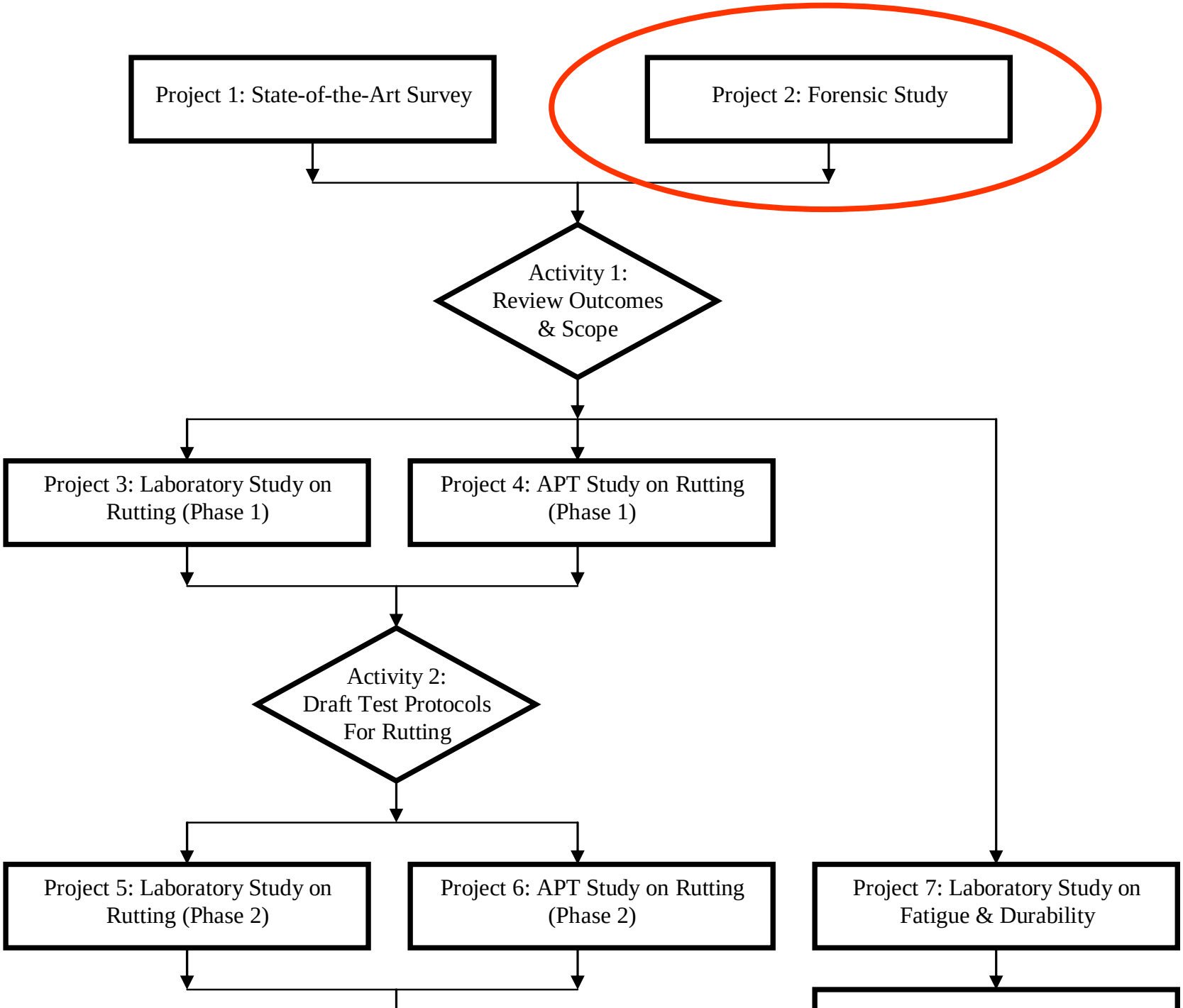
Preliminary Forensic Study

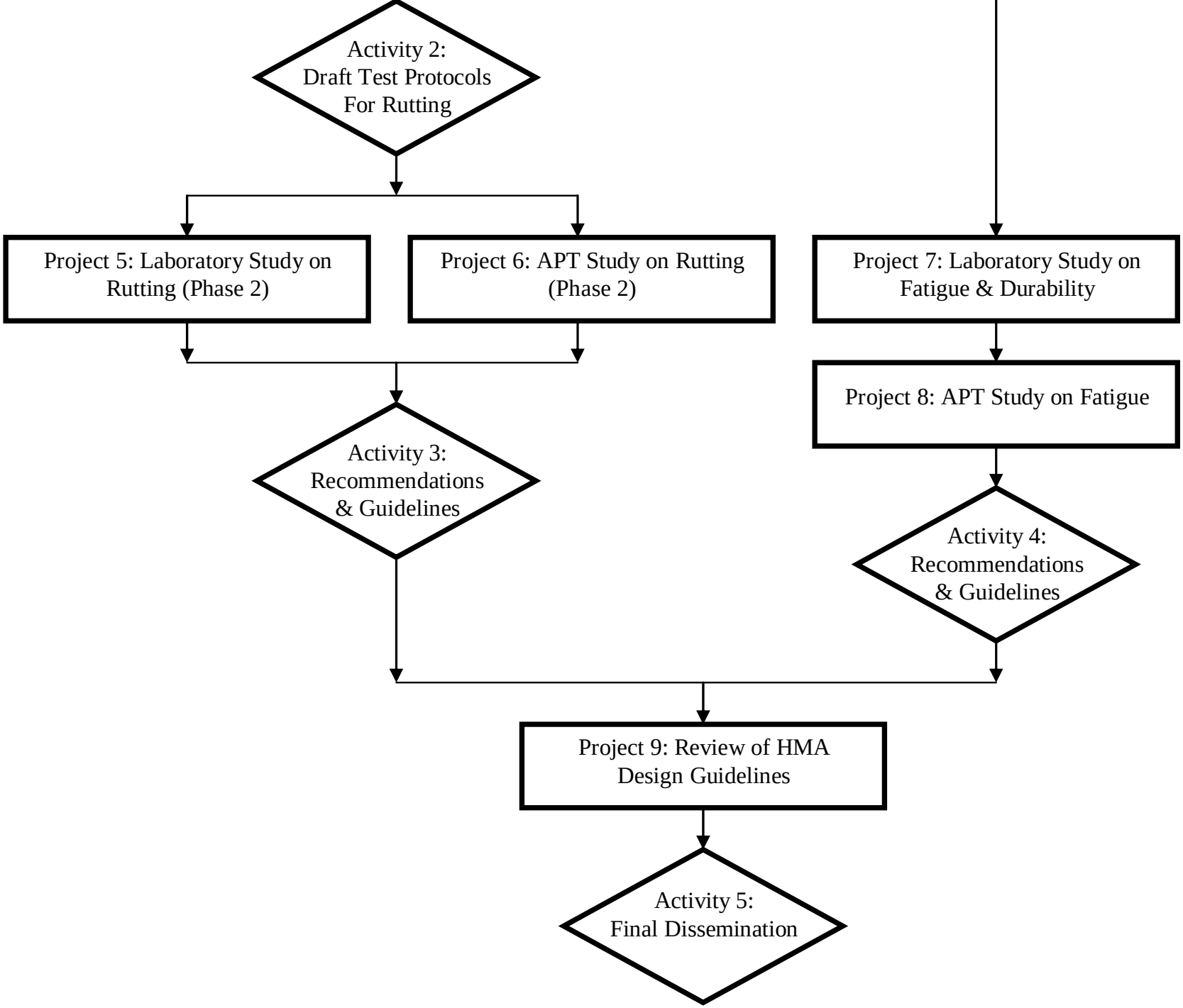
Presentation to APT Steering Committee

October 2005

Background

- HMA (interim) design guidelines (Sep ’01)
- Unresolved issues:
  - Reliable test procedures & acceptance criteria for permanent deformation & fatigue
  - Assessment of durability, including test methods & acceptance criteria for permeability
  - Relationship between contact stress & HMA performance
- Protocols for design of HMA to improve reliability in predicting performance (Nov ’04)


Project 1: State-of-the-Art Survey
Project 2: Forensic Study
Activity 1:
Review Outcomes
& Scope
Project 3: Laboratory Study on
Rutting (Phase 1)
Project 4: APT Study on Rutting
(Phase 1)
Activity 2:
Draft Test Protocols
For Rutting
Project 5: Laboratory Study on
Rutting (Phase 2)
Project 6: APT Study on Rutting
(Phase 2)
Project 7: Laboratory Study on
Fatigue & Durability


Activity 2:
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Project 6: APT Study on Rutting
(Phase 2)
Project 7: Laboratory Study on
Fatigue & Durability
Project 8: APT Study on Fatigue
Activity 3:
Recommendations
& Guidelines
Activity 4:
Recommendations
& Guidelines
Project 9: Review of HMA
Design Guidelines
Activity 5:
Final Dissemination

Purpose of the Study

- Develop methodology to facilitate identification of road section to be included in detailed forensic study
- Attempt to identify causes of failure from available data
- Assess quality of mix designs in broad terms
- Identify differentiating characteristics of good & poor performing sections
- Identify sections for detailed forensic study

Methodology

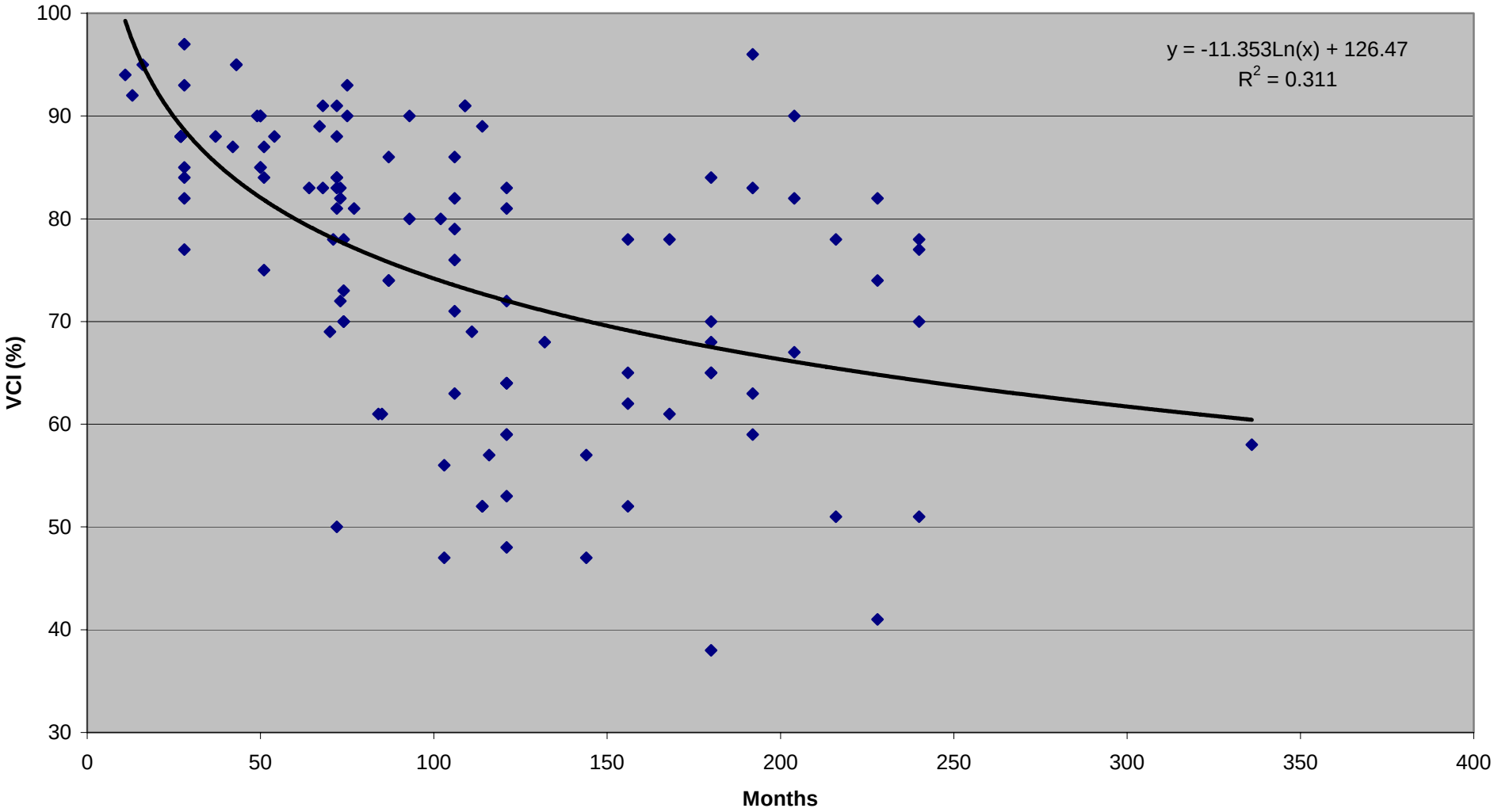
- Consult Materials database & PMS data
- Identify sections to be further studied
- Conduct visual condition assessment
- Collect & analyse mix design information
- Attempt to relate mix designs to performance
- Summarise observations & draft conclusions

Materials Database & PMS Data

- Materials database
  - Identify all road sections surfaced with HMA
  - Date of construction
- PMS database (snapshot in time)
  - Visual condition data
  - Average Annual Daily Traffic & % heavy vehicles

ASPHALT OVERLAYS FROM 1995 ONWARDS

Road	Start, km	End, km	Seal, thick-ness	Material class	Month, open	VCI	AADT	% HVS	Date
25	0.00	9.38	30	AC	2003/03	97	4887	5	07/01/2005
154	0.00	0.42	999	AC	2000/03	83	14301	3	24/06/2004
1132	4.40	12.10	25	MAC	2004/08	94	13736	7	25/02/2005
1511	0.00	8.66	999	AC	1996/09	63	36199	6	25/02/2005
2758	0.00	6.40	35	AC	2001/04	75	2362	10	21/06/2004
K15	0.00	4.89	40	AC	2001/12	95			
K15-	0.19	4.10	40	AC	2001/12	95			
K69	0.00	14.02	35	AC	2004/06	92	24498	5	07/05/2005
K91	0.00	5.00	37	AC	1999/06	83			
K111	0.00	8.20	35	AC	1996/09	86			
K146	2.50	4.46	37	AC	1999/06	72	15483	4	23/02/2005
P1/3	39.90	42.00	30	AC	1997/01	80	17423	10	21/11/2003
P2/5	1.36	1.54	30	AC	1996/01	89	15988	9	19/01/2005
P5/1	9.10	19.60	30	AC	2002/01	87	2826	30	25/10/2004
P6/2	0.60	5.70	35	AC	1998/07	61	41169	8	01/12/2003
P36/1	46.00	52.45	999	AC	1998/06	61	6389	21	25/01/2005
P41/2	0.00	36.38	20	AC	2001/05	85	10015	12	28/10/2004
P41/2	36.38	38.38	20	AC	2001/05	85	10015	12	28/10/2004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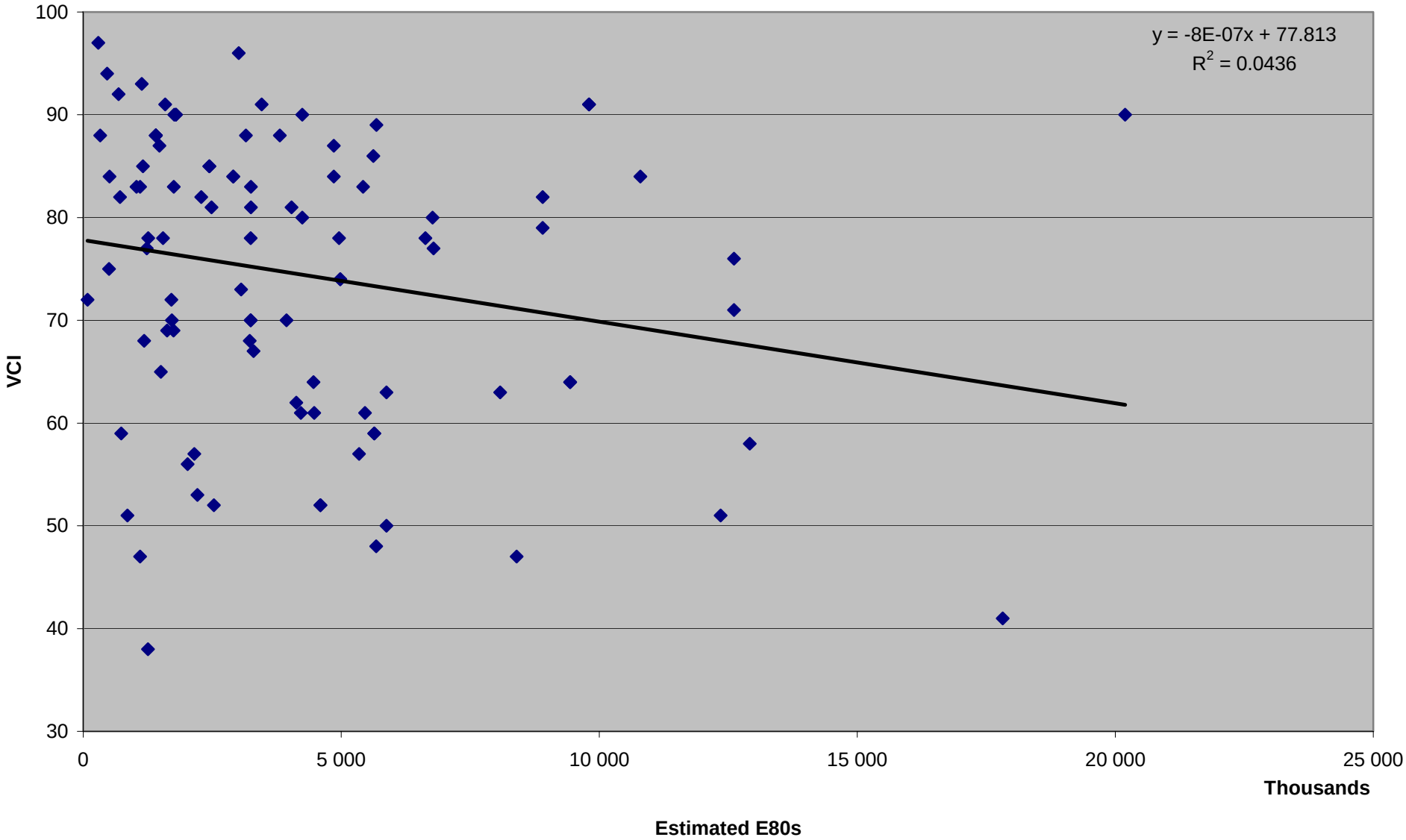
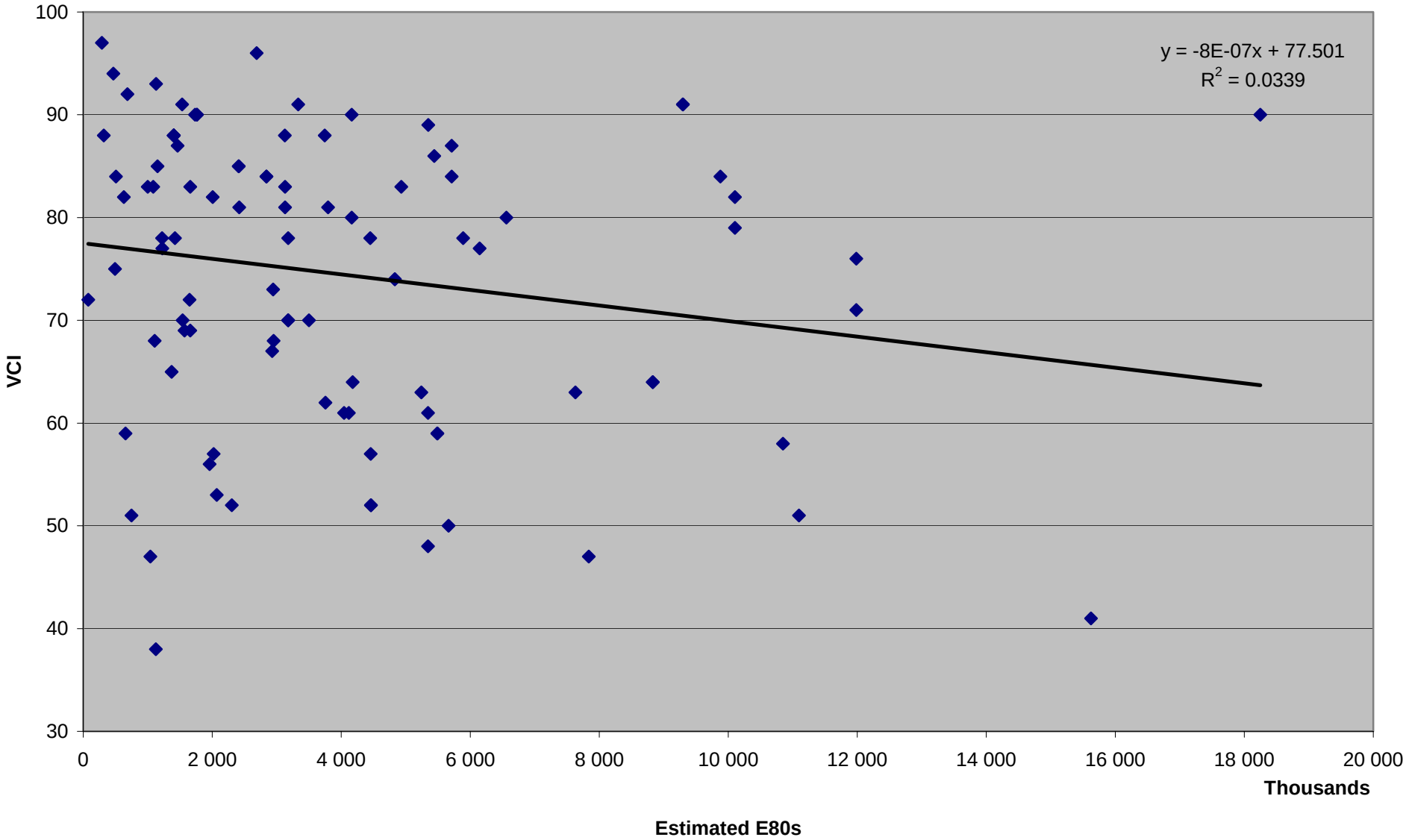
R2 = 0.311
VCI (%)
Months
100
90
80
70
60
50
40
30
0
50
100
150
200
250
300
350
400

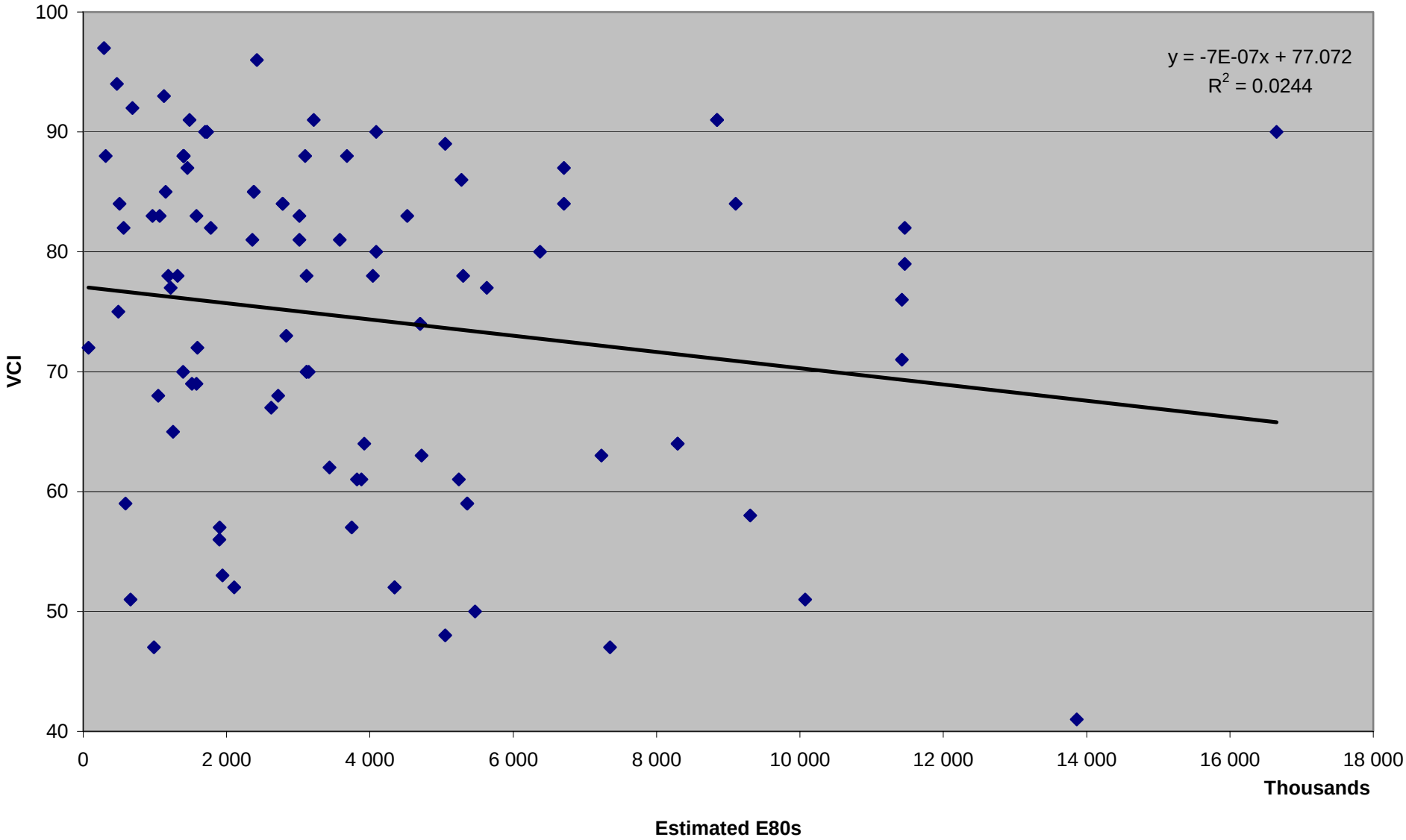
6% growth rates

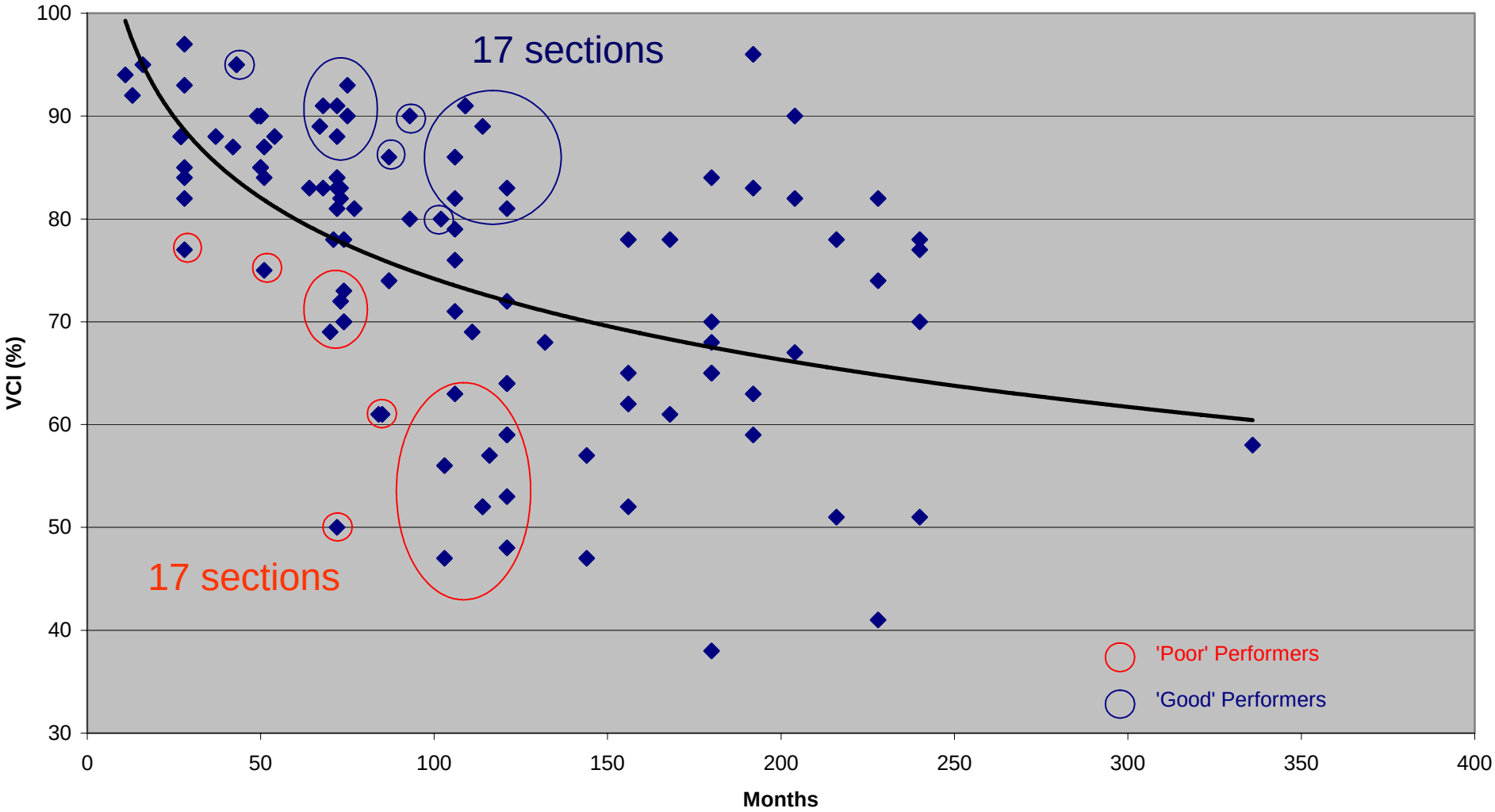


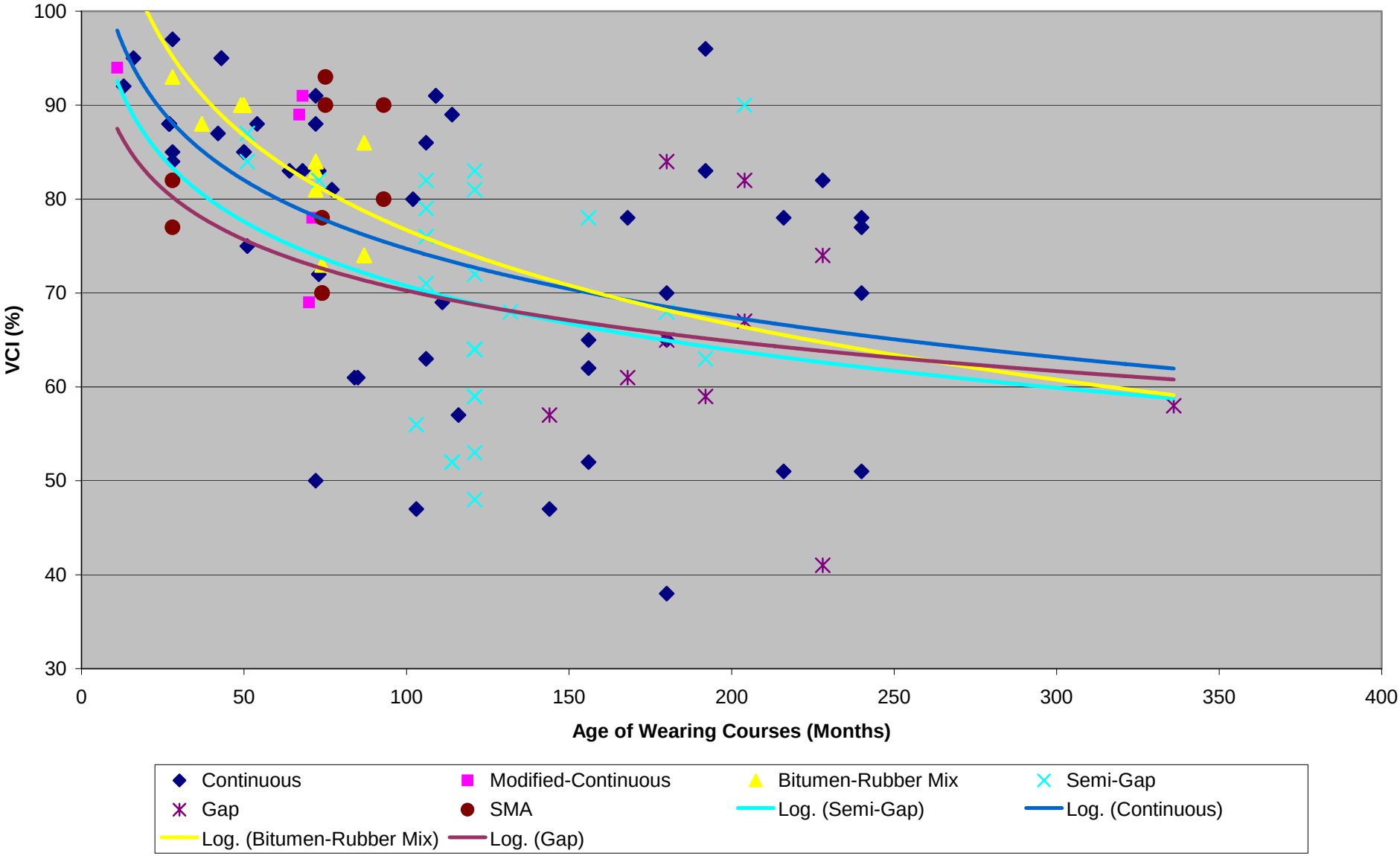
8% growth rates



10% growth rates




17 sections
17 sections
'Poor' Performers
'Good' Performers
VCI (%)
Months
100
90
80
70
60
50
40
30
0
50
100
150
200
250
300
350
400

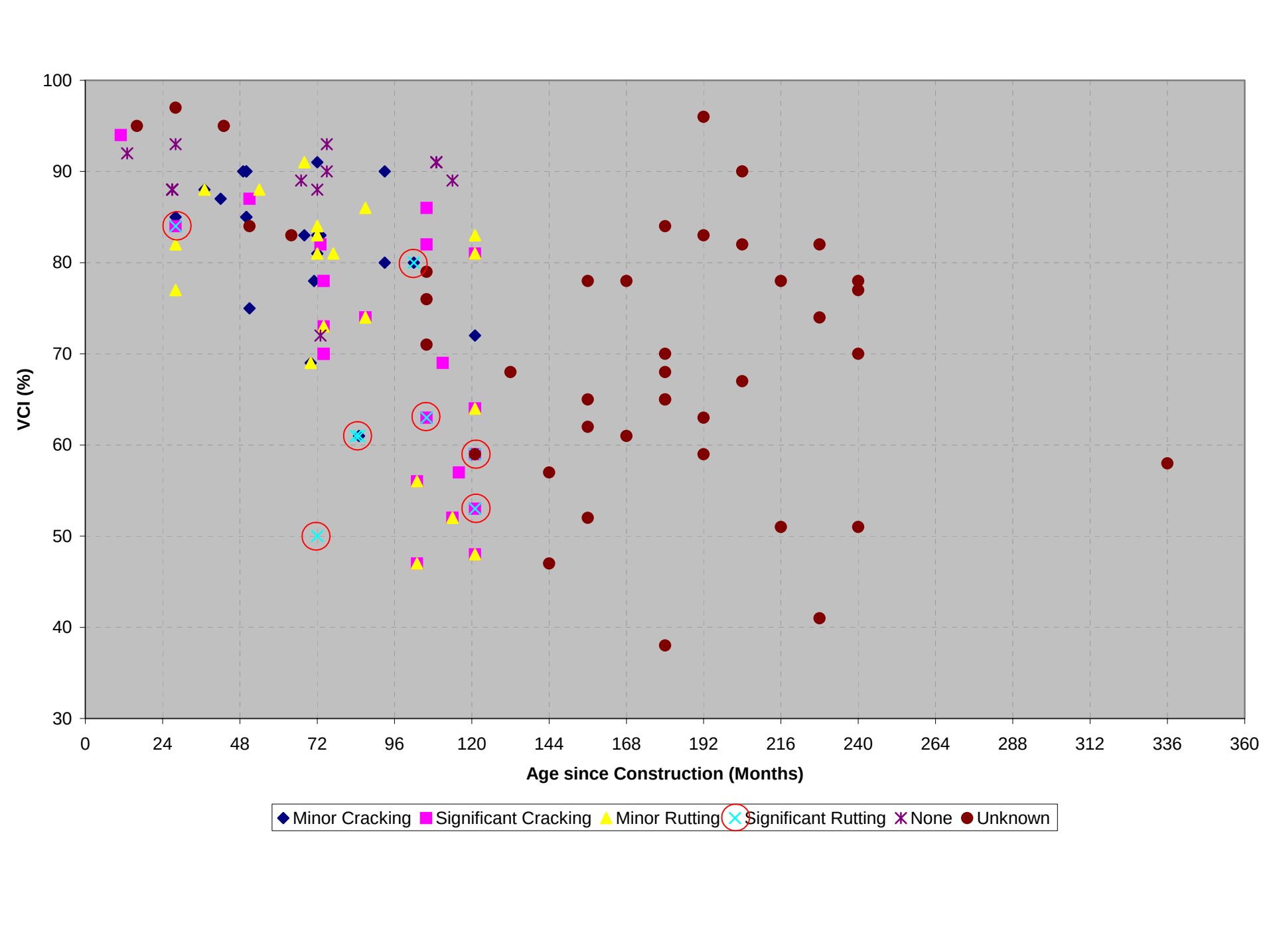

100
90
80
70
60
50
40
30
VCI (%)
0
50
100
150
200
250
300
350
400
Age of Wearing Courses (Months)
Continuous
Modified-Continuous
Bitumen-Rubber Mix
Semi-Gap
Gap
SMA
Log. (Semi-Gap)
Log. (Continuous)
Log. (Bitumen-Rubber Mix)
Log. (Gap)

Visual Assessment

- All 34 sections were assessed visually
- Observations:
  - Bituminous binder appeared dry
  - Most sections exhibited some form of cracking
  - Few sections exhibited rutting, apart from at intersections
  - Potholes observed, but to limited extent
  - Semi-gap graded mixes appeared prone to cracking (and rutting)
  - Some SMA mixes have failed prematurely, whilst others performed well

Road Sections in 'good' condition (PMS based)

Road	Material class	Month, open	VCI	AADT	Visual observations
K15	AC	2001/12	**95**		Fair condition: long cracking (deg 3, ext 2) - medium continuous
P29/1	MAC	1999/12	**89**		Good condition - medium continuous (2% SBR) (same as **P29/2** & **P101/1**)
P101/1	MAC	1999/11	**91**	1803	Good condition: slight rutting at intersection with P5/1 - med cont (2% SBR) (**P29/1 & P29/2**)
P151/1-	SMA	1999/04	**90**		Good condition - SMA
P151/1	SMA	1999/04	**93**		
P200/1-	AC	1999	**88**	40263	Good condition - medium continuous
P73/1-	AC	1999	**91**	9680	Fair: isolated crocodile cracks - medium continuous
P36/1	BRAC	1998/04	**86**	48485	Good condition: slight rutting in slow lane (deg 1, ext 1) - Superpave (bitumen-rubber)
P157/2	SMA	1997/10	**90**	57556	Fair condition: long cracking (deg 3, ext 2) - SMA (3% SBR)
P157/2-	SMA	1997/10	**80**	57556	
P1/3	AC	1997/01	**80**	17423	Poor condition: long/trans cracking (deg 3/4, ext 2) & rutting (deg 3, ext 2) - continuous
K111	AC	1996/09	**86**		Poor condition: long/trans cracking (deg 3, ext 2/4) & edge breaks - med continuous
P156/1	AS	1996/09	**82**	33720	Poor condition (long/trans/croc cracking; pumping; edgebreaks) - semi-gap (3% SBR)
P156/1	AC	1996/06	**91**	33720	Good condition - medium continuous
P2/5	AC	1996/01	**89**	15988	Resealed in June 2005; info incorrect
P67/1	AS	1995/06	**81**	24198	Poor condition: long/trans cracking (deg 3, ext 2/4) & rutting (deg 3, ext 1) - semi-gap
K175	AS	1995/06	**83**	2929	Fair condition: rutting (deg 2, ext 2) - semi-gap


100
90
80
70
60
50
40
30
VCI (%)
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
360
Age since Construction (Months)
Minor Cracking
Significant Cracking
Minor Rutting
Significant Rutting
None
Unknown

Visual assessments: conclusions

- Binder ageing:
  - Reassess bitumen specifications
  - Change design & density specs
  - Capping of HMA (sealing)
- Free-flowing conditions: higher binder content
- More rut resistant designs for intersections
- Greater use of SMA should be encouraged, where appropriate

Asphalt Mix Design

- Comments on relationships between mix design & performance are based on incomplete sets of data:
  - No certainty on status of mix design
  - No As-Built data
  - No performance/traffic data over time
  - No field sampling/testing

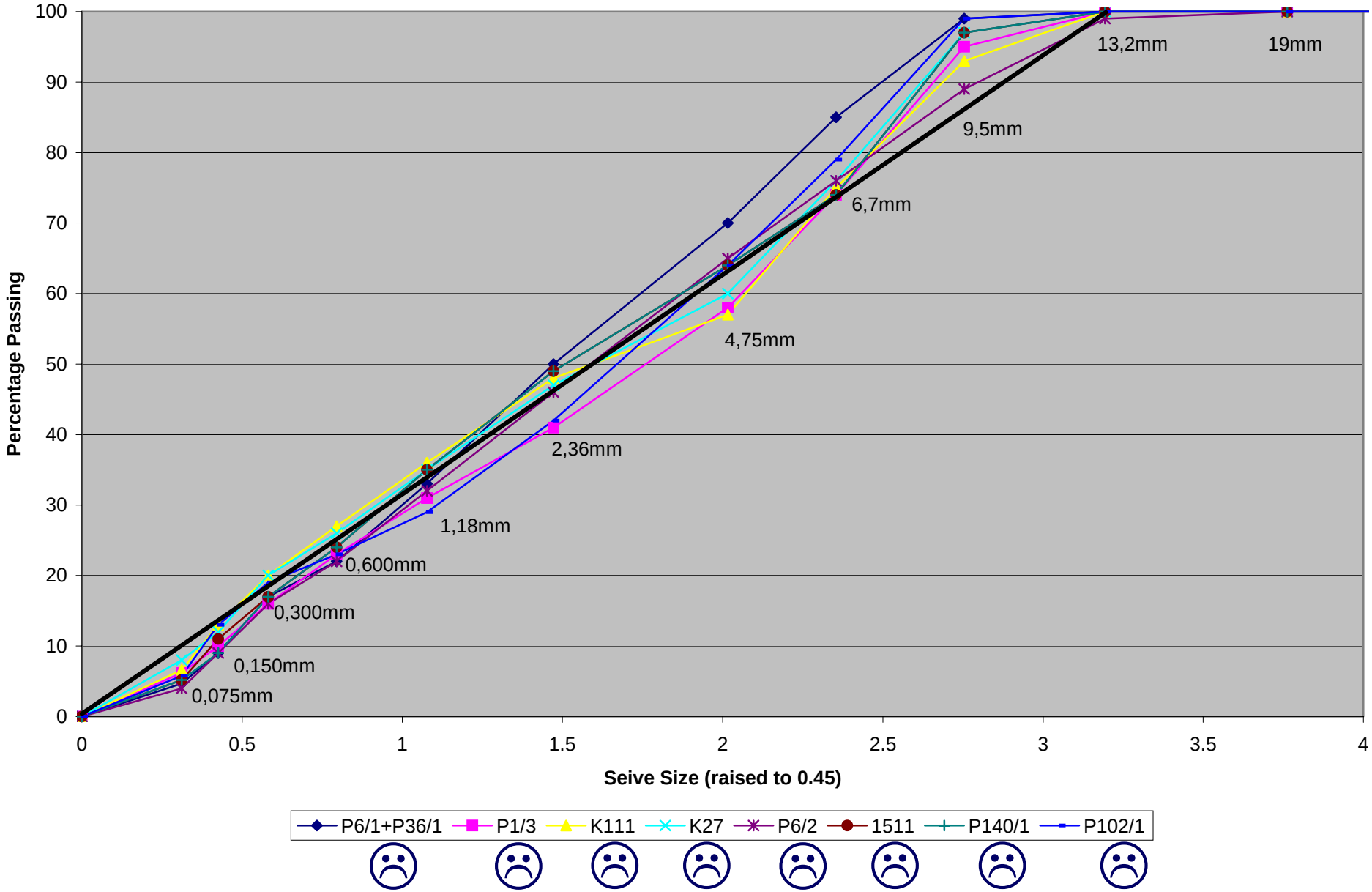
Asphalt Mix Design

- General observations/concerns:
  - Process of acceptance of job mix not always clear
  - Off-the-shelf “recipe” designs used over extended periods of time (changes in aggregate, particularly fine aggregate?)
  - Application of “same” mix design on low & high trafficked roads and on different types of support
  - Sometimes ‘arbitrarily’ selection of optimum binder contents
  - “Increase B/C if mix is subjected to higher traffic”?

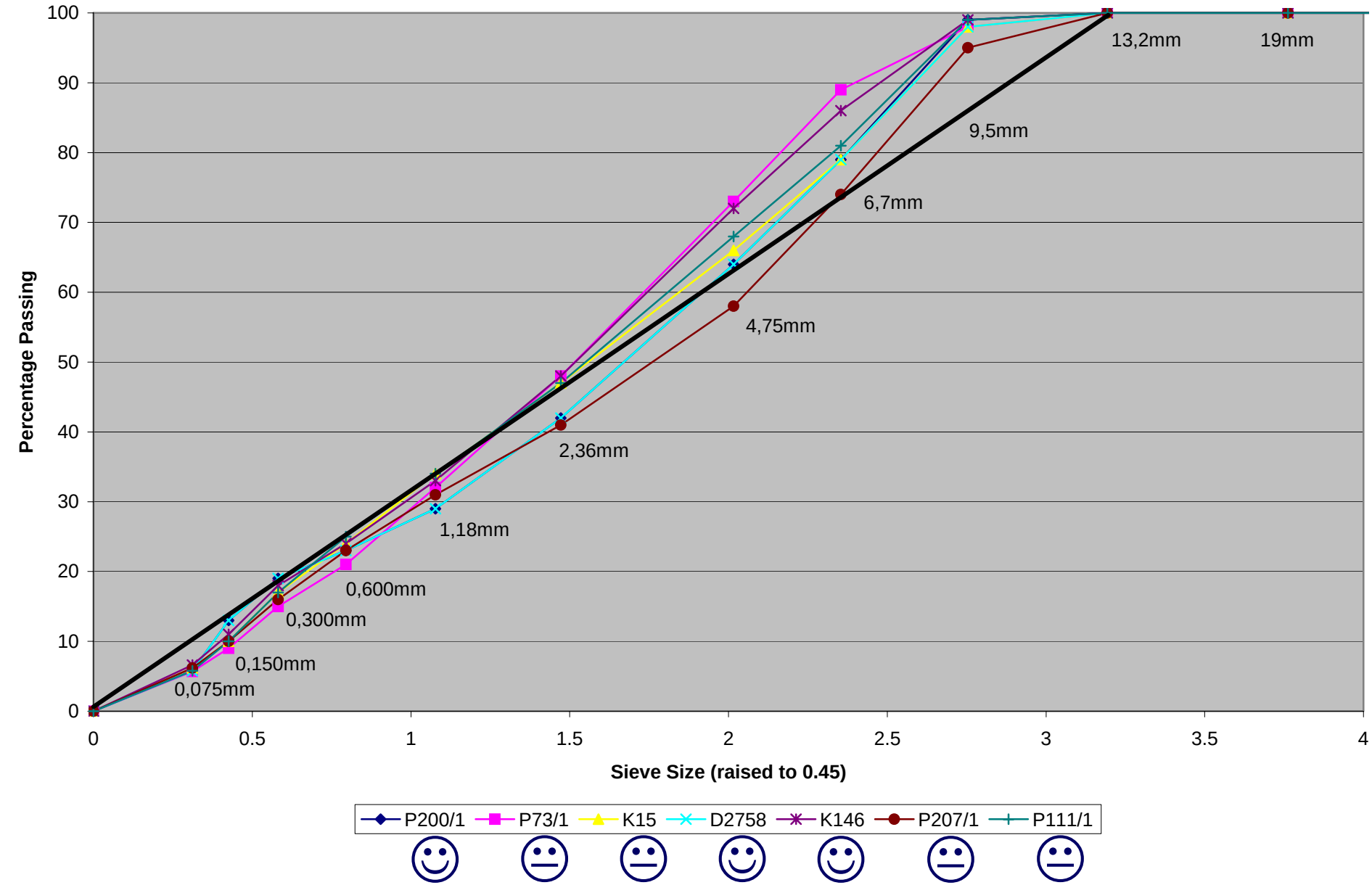
Continuously Graded Asphalt

- Observations
  - Filler contents of ‘good’ performing mixes in narrow band (5.7 to 6.6% vs 4.0 to 8.0%)
  - ‘Poor’ performing mixes: discontinuities in grading
  - Some ‘Poor’ performing mixes: high $P_{2.36mm}$
  - No meaningful relationships between mix design data & performance
    - Marshall stability: 10-15 kN ; Flow: 2.4-3.4 mm
    - ITS > 900kN ; Dyn/Static creep > minima specified
    - VMA on wet side: 2x ruts, but 1x ‘good’

Continuously Graded Asphalt: ‘poor’ performance



Continuously Graded Asphalt: ‘fair/good’ performance

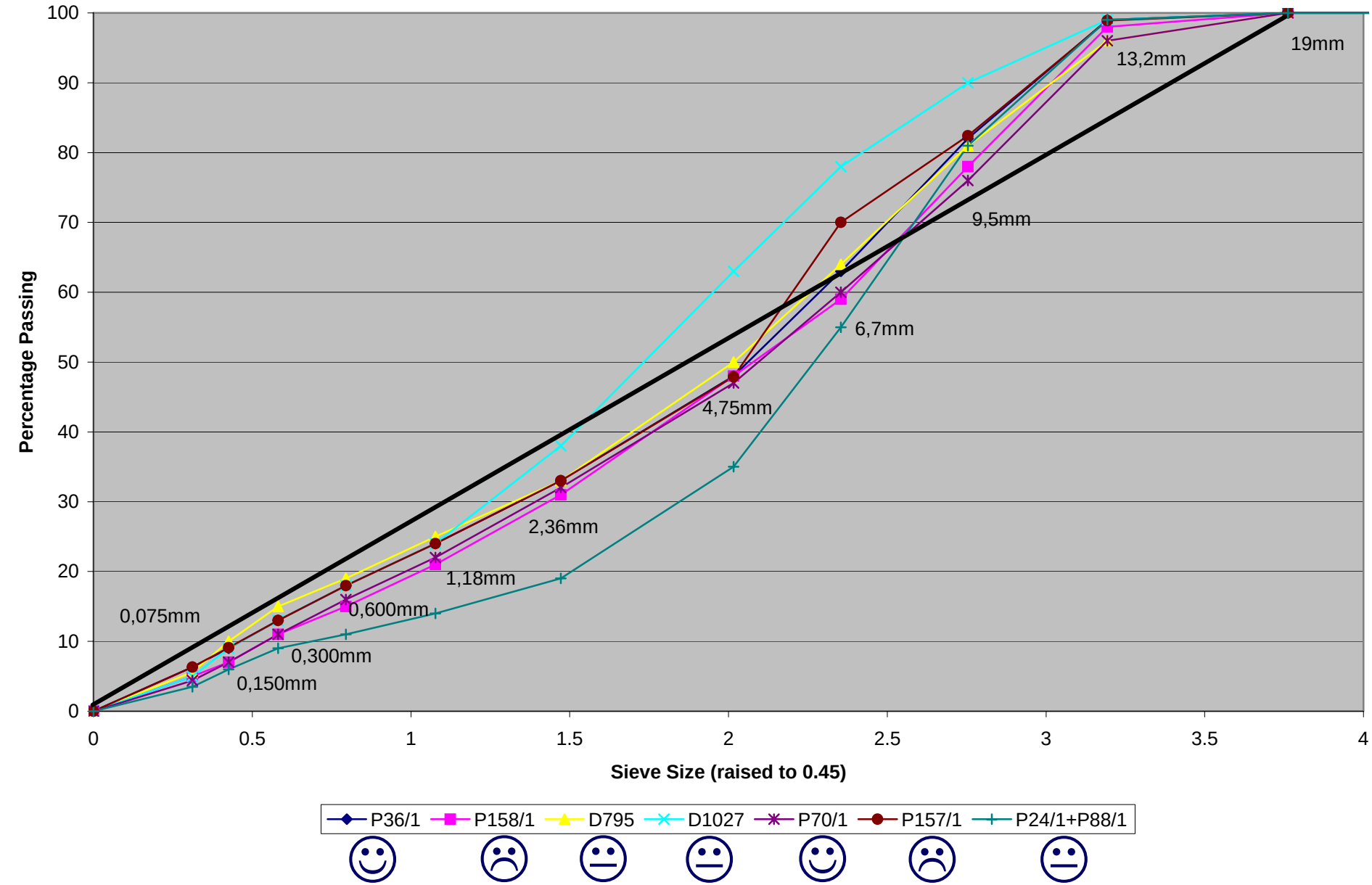


	Continuous 60/70 P6/1+P36/1	Continuous 60/70 P1/3	Continuous 60/70 K111	Continuous 60/70 **K27**	Continuous 60/70 P6/2	Continuous 60/70 1511	Continuous 60/70 P140/1	Continuous 60/70 **P102/1**
B/C	5.5	5.3	5.5?	5.5	5.5?	5.5??	5.5	5
Voids	**5.4**	4.2	4.1	4.4	4.8	4.8	4.8	4.6
VMA	16.4	15.8	15.9	15.8	16.5	16.6	16.6	**15.3**
VMA	**wet**	min	dry?	dry	min	min	min	dry
VFB	70.1	73.4	74.1	72.5	70.8	67.3	67.3	70
B.Film	8.8	8.2	6.9	6.7	9.2	7.2		7.0
F/B ratio	**0.9**	1.2	1.2	1.4	0.7	0.9	0.9	1.2
stability	13.1	10.1	12.3	11.7	11.3	12	12	10.9
flow	3.4	**3.1**	3	2.4	3.2	2.8	2.8	2.8
stab/flow	3.9	3.3	4.1	4.9	3.5	4.3	4.3	3.9
ITS	900	1089	1233	1172	1187	991	991	1086
Stat.Crp	-	354	322	240	-	170	170	264
Dyn.Crp	32	**10**	30	43	-	39	-	32
min VMA	16.4	15.2	15.1	15.4	15.8	15.8	15.8	**15.6**
VFB				65-75				
Age	5	8	9	6	7	9	10	2
Rating	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
PMS	Poor	Good	Good	Poor	Poor	Poor	Poor	Poor
Distress	Crack/Rut	Crack/Rut	Lo/Tr Crack	Rutting	Rutting	Crack/Rut	Cracking	Crack/Rut

Bitumen-Rubber Asphalt

- Generally good performance considering the purpose of their application
- Wide variety of gradings used successfully
- Bitumen-rubber mixes less sensitive to grading than unmodified counterparts (?)
- Generally very high VMAs (>18%), VFB (>75%), film thicknesses (>10µm)

Bitumen-Rubber Asphalt

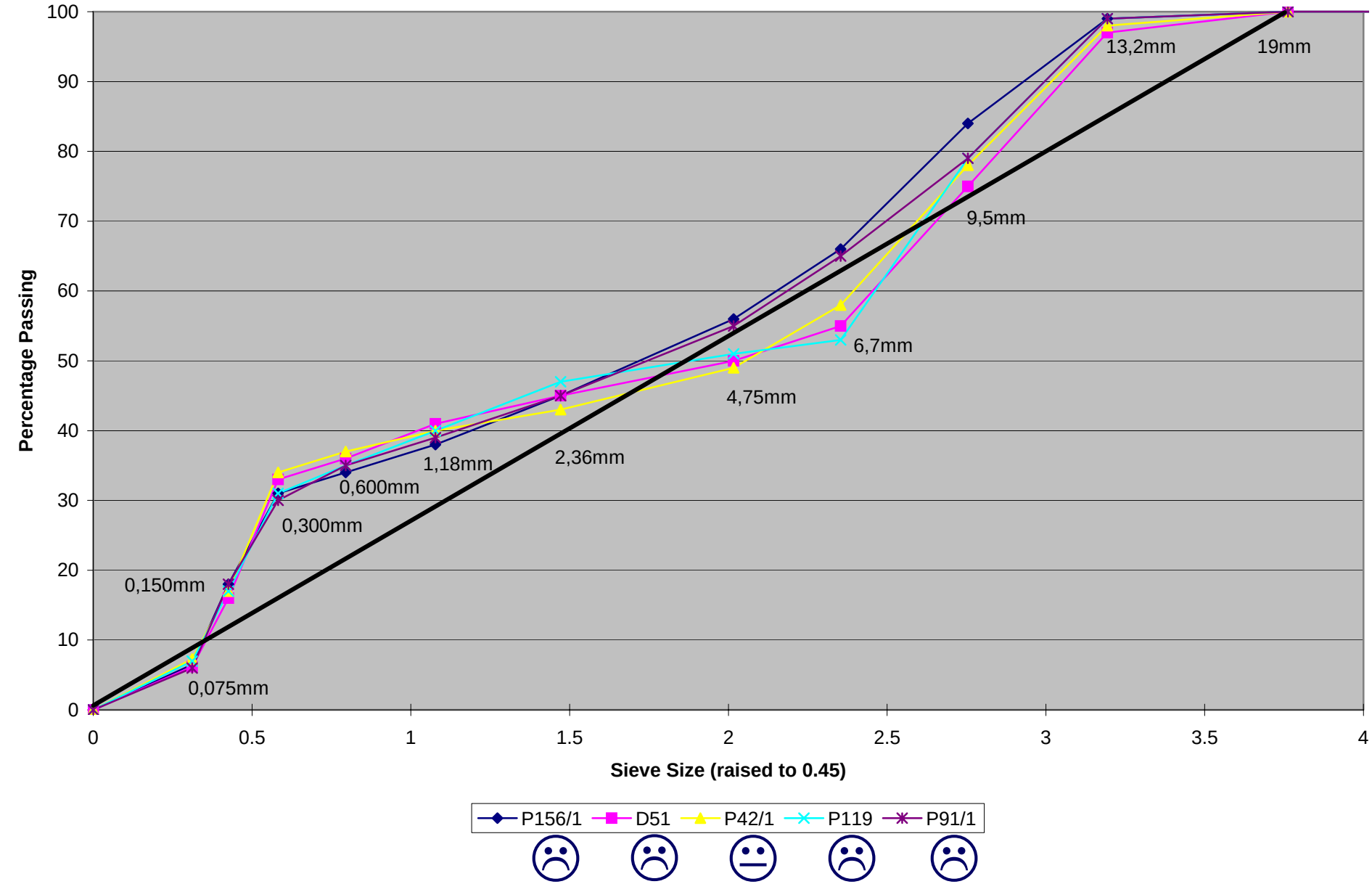


	Superpave Bit-Rub **P36/1**	Continuous Bit-Rub **P158/1**	Continuous Bit-Rub D795	Continuous But-Rub D1027	Continuous Bit-Rub P70/1	Superpave Bit-Rub P157/1	Continuous Bit-Rub P24/1+P88/1
B/C	6.5	7	6.7	6.5	6.5	6.5	8
Voids	4.4	4.5	3.9	4.4	4.2	4.4	6.5
VMA	**18.2**	**18.6**	**18.0**	17.6	**18.7**	**18.2**	**20.2**
VMA	**wet**	?	**wet**	wet?	wet?	wet?	min
VFB	**75.9**	**76**	**78**	74.9	**77.3**	75.9	67.7
B.Film	**10.8**	**14.1**	**11.1**	**11.2**	**13.3**	**10.8**	**16.1**
F/B ratio	1.0	0.7	0.8	0.8	0.7	1.0	0.4
stability	7.8	8.3	8.7	8.8	9.7	7.8	7.3
flow	3.3	3.2	3.2	3.1	3.9	3.3	4.1
stab/flow	2.4	2.6	2.6	2.2	2.5	2.4	1.8
ITS	1094	411	1200	529	757	1094	632
Stat.Crp	-	-	-	-	-	-	58
Dyn.Crp	-	17	-	-	-	-	-
min VMA VFB	**14.4**	**14.5**	**13.9**	15.4	**14.2**	**14.4**	**16.5**
Age	7	6	3	4	2	7	6
Rating	Good	Poor	Fair	Fair	Good	Poor	Fair
PMS	Good	Poor	Good	Good	Good	Fair	Fair
Distress	slight rutting crushed st	Crack/Rut crushed st	cracking cemented	cracking cemented	None unknown	Crack/Rut crushed st	Crack/Rut gravel

Semi-Gap-Graded Asphalt

- 4 out of 5 mixes rated ‘poor’ with cracking most dominant mode of failure
- No discernable effects of grading on performance
- Relatively low binder film thicknesses, despite fairly high VFB
- Greater amounts of fines → greater particle surface area → low binder film thicknesses → ‘dry & brittle mixes’ with lesser resistance to cracking (?)

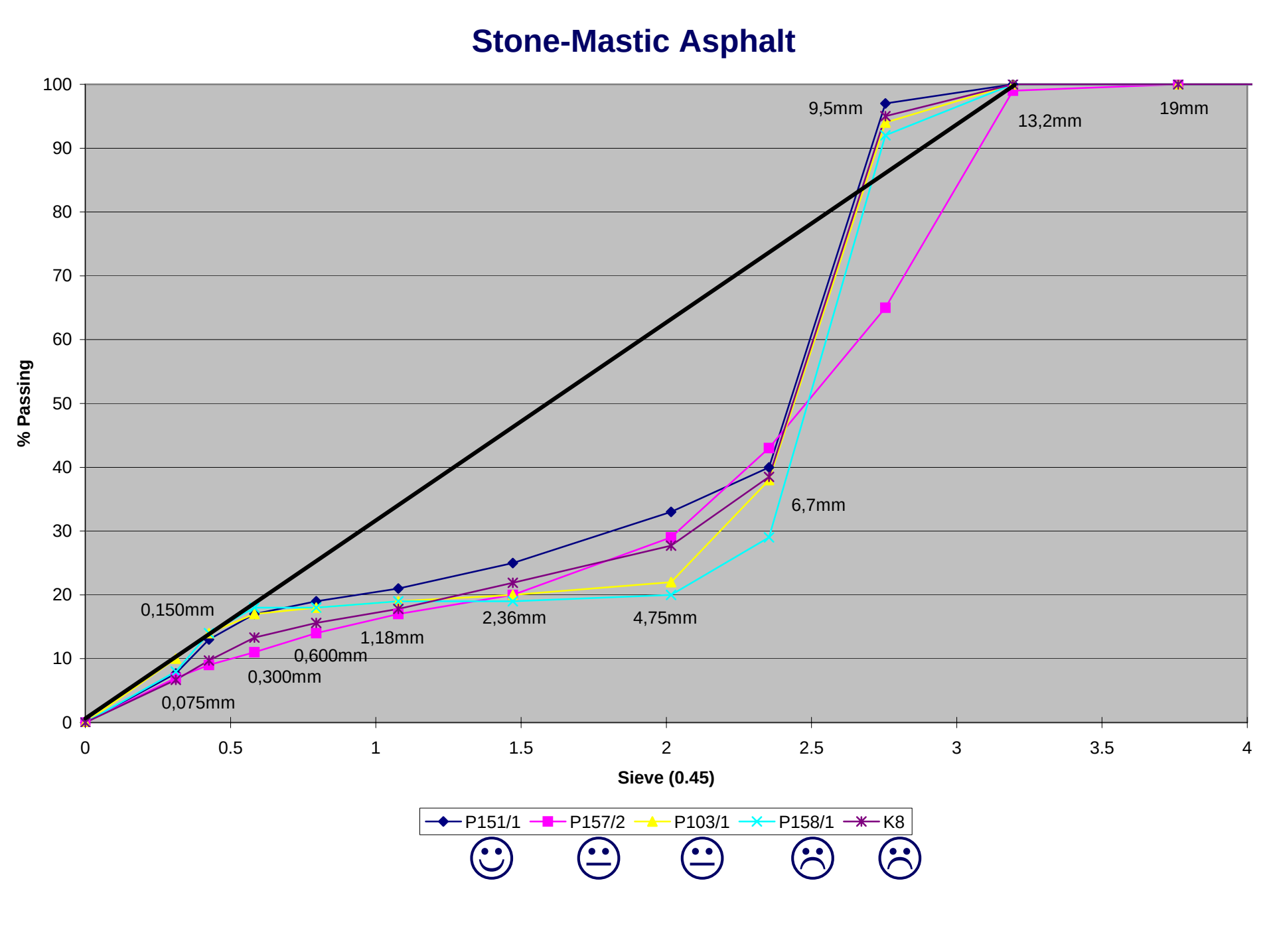
Semi-Gap Graded Asphalt



	Semi-gap 60/70+SBR P156/1	Semi-gap 40/50 D51	Semi-gap 40/50 **P42/1**	Semi-gap 60/70 P119	Semi-gap 40/50 P91/1
B/C	5.7	5.8	5.7	6	5.7?
Voids	6.1	4.3	4	4.4	5.2
VMA	18.7	17.6	15.8	17.7	18.1
VMA			min		min
VFB	66	73	74.7	74.4	71.4
B.Film	6.2	6.6	5.7	6.7	5.7
F/B ratio	1.1	1.1	1.3	1.2	1.1
stability	8.5	11.1	10.5	10	11
flow	2.1	3.3	3.2	2.6	2.2
stab/flow	4.0	3.4	3.3	3.8	5.0
ITS	1143	-	-	1351	1037
Stat.Crp	134	-	-	-	-
Dyn.Crp	-	-	-	69	-
min VMA	15.1	14.3	14	14.4	15.2
VFB range			65-75		
	9 Poor Cracking crushed st	10 Poor Cracking crushed st	9 Fair Crack/Rut cemented	10 Poor Cracking crushed st	9 Poor Cracking crushed st

Stone-Mastic Asphalt

- Designers appear not to have a proper handle on how to design SMAs
  - 3 out of 5 mixes: design void content > 6%
  - Attempts made to meet COLTO requirements (!)
  - Optimum binder content on wet side of VMA
  - VCA not reflected on design sheets
- Development of mix design procedure for SMA is a priority


Stone-Mastic Asphalt
% Passing
Sieve (0.45)
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3
3.5
4
0,075mm
0,150mm
0,300mm
0,600mm
1,18mm
2,36mm
4,75mm
6,7mm
9,5mm
13,2mm
19mm
P151/1
P157/2
P103/1
P158/1
K8

	SMA **P151/1**	SMA P157/2	SMA P103/1	SMA **P158/1**	SMA K8
B/C	6.2	6.5	6.5	6.7	5.8
Voids	5.5	4.6	**6.7**	**6.3**	**6.5**
VMA	18.6	19.4	21.1	20.4	18
VMA	min	wet	wet	min	?
VFB	70.3	**76.1**	68.4	69.0	**64.2**
B.Film	9	12.4	8.9	9.5	10.3
F/B ratio	1.2	1.1	1.6	1.2	1.2
stability	6.7	6.8	-	6.4	5.4
flow	3.1	3.2	-	3.4	3.6
stab/flow	1.8	2.1	-	1.9	1.5
ITS	662	699	-	870	-
Dyn.Crp	-	63	-	-	-
min VMA	17	17	17	17	17
VFB			65-75		
Age	14	8	5	6	6
Rating	Good	Fair	Fair	Poor	Poor
PMS	Good	Good	Poor	Poor	unknown
Distress	None	Long Crck	slight rutting	Cracking	Rutting
support	crushed st	gravel	crushed st	crushed st	unknown

Main Outcomes

- Mix designs to be better aligned to design environment
- More attention to be given to gradings
  - Smooth gradings (continuous)
  - Limit filler content to close bands (continuous)
  - Be aware of high percentage of fines
- More rut resistant mixes for intersections
- Design protocols for SMA to be developed/ refined

Sites for Detailed Forensic Study

- ‘Poor’ performing road sections
  - P158/1: SMA (1999)
  - P158/1: Bitumen-rubber asphalt (1999)
  - K27: medium continuous (1999)
  - P42/1: Semi-gap (1996)
  - K8 (intersection): SMA (1999)
  - P102/1: medium continuous (2003)
- ‘Good’ performing road sections
  - P151/1: SMA (1999)
  - P200/1: medium continuous (1999)
  - P36/1: bitumen-rubber asphalt (1998)
  - P111/1: medium continuous (2001)

HMA Forensic Study (Phase 2)

Objectives

- Validation of interim findings of Phase 1
- Better understand relationships between mix design, construction and performance
- Identify typical causes and mechanisms of failure
- Interim recommendations on selection and design of HMA for specific conditions
- Review scope of HMA research plan and draft proposals for way forward

Methodology

- Review outcomes of preliminary forensic study with industry
- Desktop study on pavement sections identified in Phase 1
  - As Built data
  - Performance records (PMS historical data)
  - Traffic records
- Non-destructive testing of road sections
  - FWD and DCP
  - Review appropriateness of selected road sections for laboratory study

Methodology

- Field/Laboratory study
  - Extract slabs & cores from pavement
  - Determine volumetric & engineering properties
  - Determine binder physio-chemical properties
  - Fatigue & rutting properties
  - Identify causes and mechanisms of failure & attributes of good performance
- Final report & review/redraft HMA research plan

APT Study into Permanent Deformation

Outline

- Purpose
  - Address one of the recommendations of preliminary forensic study, namely to identify suitable products for use at intersections
- Methodology
  - Open invitation to asphalt sector to propose rut-resistant product to be placed on trial section
  - Identify suitable site for construction of sections
  - Subject products submitted + reference mix to APT
  - Subject reference mix to various combinations of tyre pressures and axle loads to assess their impact on rutting
  - Parallel laboratory study to assess suitability of test methods to predict rutting